LA-UR-03-DRAFT

Advanced Fuel Cycle Initiative
Semi-Annual Technical Review

- Lead-Alloys Coolant Technology

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Los Alamos National Laboratory

Outline

- Integration with Gen IV LFR/SSTAR
- Work Packages Milestone Performance and Outlook
- Technical Achievements Highlight
- University Collaboration and International Cooperation
- Conclusion

Contributions from Many Team Members and Collaborators

- Valentina Tcharnotskaia, Mike Madrid, Keith Woloshun - DELTA Loop
- Wei Hang - Oxygen sensors
- Scott Lillard, Mike Paciotti - Characterization of oxides
- Jinsuo Zhang - Corrosion modeling
- Jim Lime, Jinsuo Zhang - TRAC modeling of DELTA
- Stuart Maloy, Peter Hosemann - Preparation and analysis of test specimens

- Gary Was, GRAs/PD, U. Michigan - Heavy ion irradiation to simulate spallation environment
- Jim Stubbins, Alan Bolind, U. Ill, U-C - Corrosion probe
- Darryl Butt, GRAs, U. Florida - Irradiation effects on oxides
- Frank Harmon, staff, IAC - E-beam irradiation of oxygen sensors
- Ron Ballinger, GRA, MIT - Fe-Si/Fe-Cr-Si alloys, ODS materials for enhanced corrosion resistance
- Todd Allen, ANL - Test (fusion) materials
- John Farley, Allen Johnson, Ajit Roy, Samir Moujaes, Yitung Chen, Yingtao Jiang, Bingmei Fu, Woosoon Yim, Tony Hechanova, Gary Cerefice, and students, UNLV - corrosion analysis, mechanical/corrosion properties, corrosion and hydrodynamics, sensors, LBE test loop and facility, etc

Integration with Gen-IV LFR Coolant Technology R&D

- Transitioned a fraction of the SOW in DELTA Loop Operation and LBE Research work packages into Gen IV LFR/SSTAR program from the third quarter of FY03

- Joined the development of LFR/SSTAR project; planning and leading coolant technology development

Milestone Performance in 2nd-3rd Quarters, FY03
DELTA Loop Operation and Experiments

Milestones	M/S Level	Baseline	Status/Outlook
Loop conditioning and attended operation to test long term operation stability	4	4/4/03	Completed (Include oxygen sensor seal development and testing)
Initiate DELTA loop 1000 hr materials test	4	7/15/03	Just started (Loop and LBE contaminated with excess oxides and oxygen during shakedown operations; action plan proposed for change of SOW and schedule to include cleanup and restoration test and development before testing)
Complete DELTA Loop 1000 hr materials test	3	9/15/03	Delayed (see above)
Thermal hydraulic test preliminary design	4	8/15/03	Completed
Thermal hydraulic test final design	4	9/29/03	Will complete on schedule

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Milestone Performance in 2nd-3rd Quarters, FY03
LBE Research

Milestones	M/S Level	Baseline	Status/Outlook
Analysis report for irradiation experiment on oxide of HT-9	4	1/03	Completed
Summary of preconditioning oxidation parameters investigated	4	4/03	Completed
Delivery of oxygen sensors to international partners	4	7/03	Delayed (CEA proposed delay till 12/03)
Initial analysis of the corrosion test specimens (including effects of Si)	4	8/03	Partial completion – analysis on control specimens performed, new specimens prepared
Deliver available LBE data and operational experience to LBE handbook	4	8/03	To be completed (compiling Russian and international materials database)
Corrosion probe seals tested in LBE flow	4	9/03	Will complete on schedule
Complete TRAC model for LBE benchmark	4	9/03	Completed

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Technical Achievement Highlights

- Improvement of instrumentation for DELTA Loop application
- Development and testing of loop and coolant restoration methods to remove excess oxides and oxygen
- Characterization of pre-oxidation of HT-9 and 316SS
- Application and publication of corrosion modeling results (5 journal articles)
- Design of new sensor assembly and a calibration stand
- Selection of thermal hydraulic test conditions in DELTA Loop (natural convection) through TRAC
- Expansion of test specimens (materials and configurations)
- Compilation of Russian materials database for lead-alloys cooled nuclear systems and international LBE corrosion test results

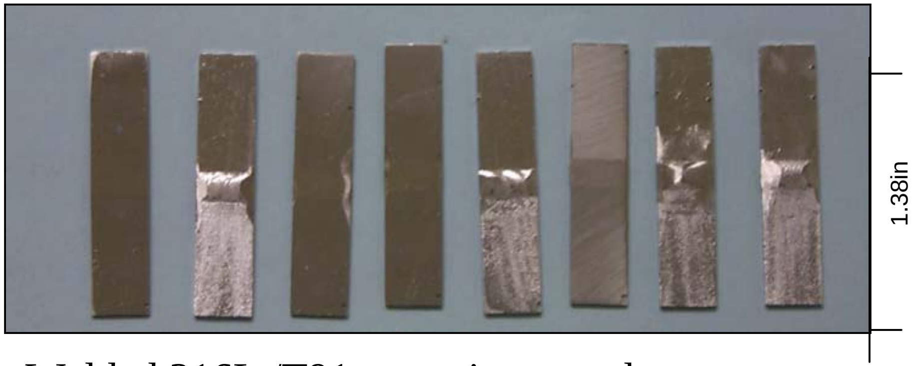
Developing and Improving Sensors and Instrumentation for DELTA Loop

- Reliable pressure transducers have worked consistently for over 200 hours and 20 cycles
- Venturi flow meter reads consistent lead-bismuth flow rates
- New oxygen sensor design provides superior sealing.

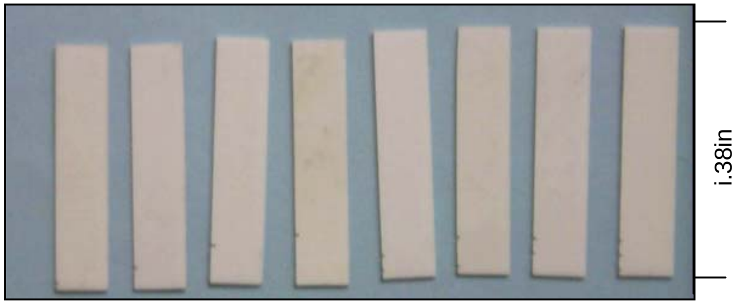



Material Test Specimens are Ready

- Material Samples of Stainless steels 316L, HT9, T91, EP823, 316L welded to T91 and Tantalum, Iron, Iron-Silicon alloys, Alumina are ready for testing.



Welded 316L /T91 corrosion samples

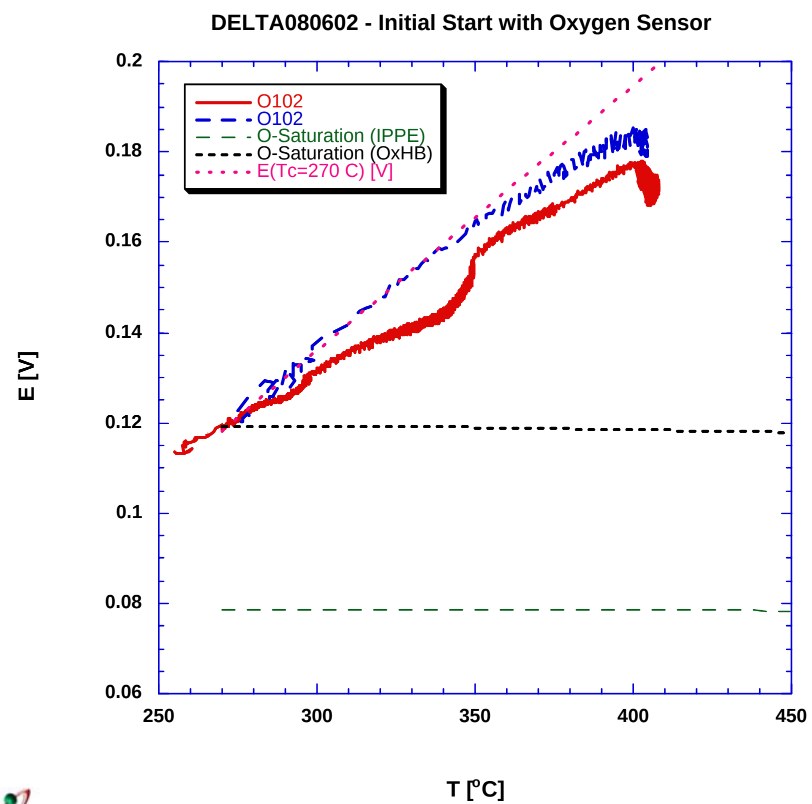


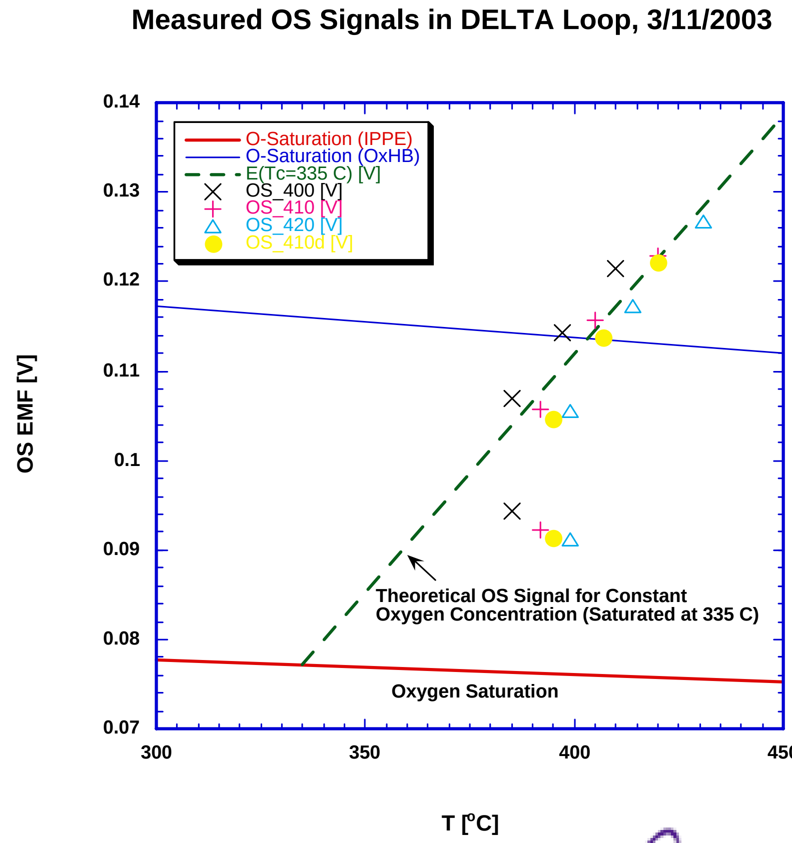
Alumina corrosion samples

HT9 tensile samples

Developing and Testing Loop and Coolant Restoration Methods in DELTA Loop

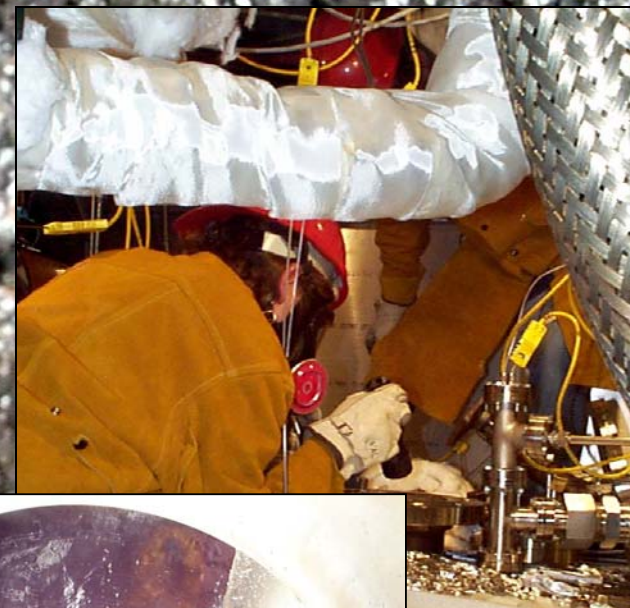
- The oxygen concentration increased from 8.7e-6 wt% (T_{sat}~270°C, 08/02) to 5.5e-5 wt%(T_{sat}~350°C, 03/03)





Epic Battle with Oxygen in DELTA Loop

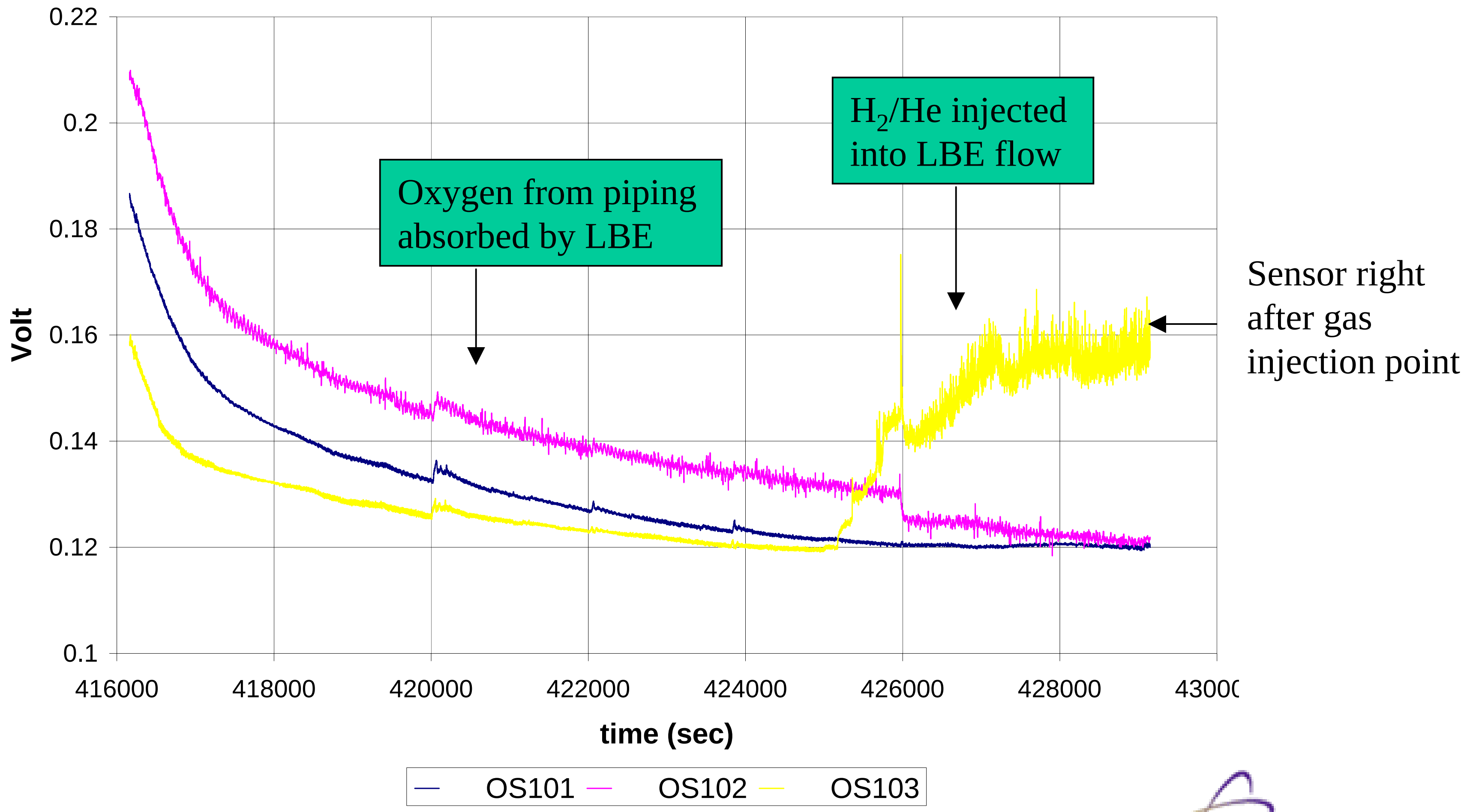
- Manual oxide removal
- Over 50 hours of 6%H_2/94%He injection into flow
- Over 200 hours of cleaning gas injection into melt tank



Oxygen Sensors Show Loop Oxygen Contamination

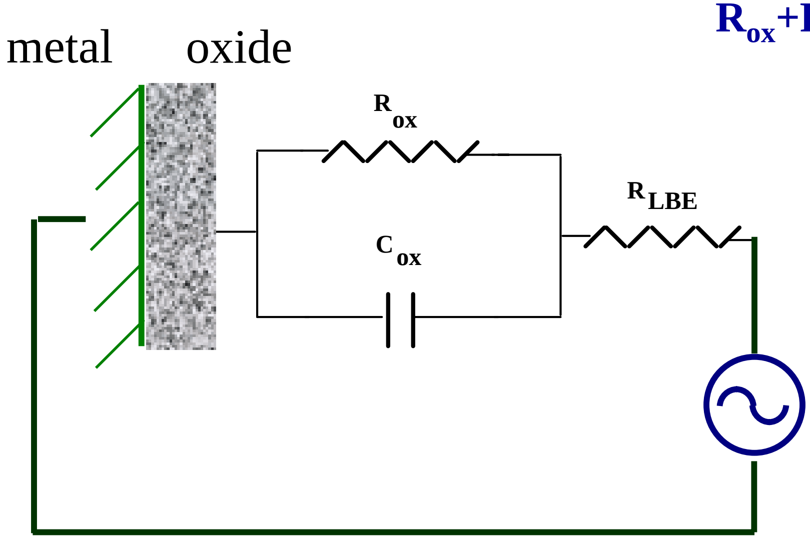
- After cleaning oxygen sensors readings increase showing reduction in oxygen content
- After running in the loop for several hours sensors show oxygen saturation levels again
- Conclusion: Loop piping is covered in oxides (confirmed with visual inspection).

Example of Oxygen Sensors Readings

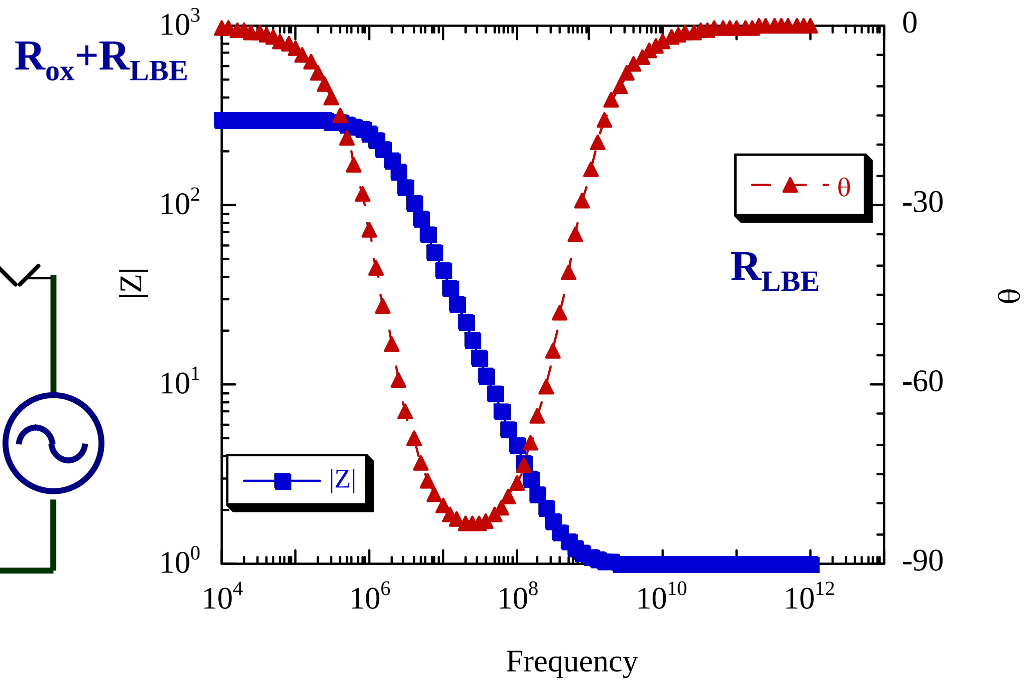


Using Dielectric Properties of Oxide to Measure Corrosion Online/In-situ

Electrical equivalent circuit for LBE system



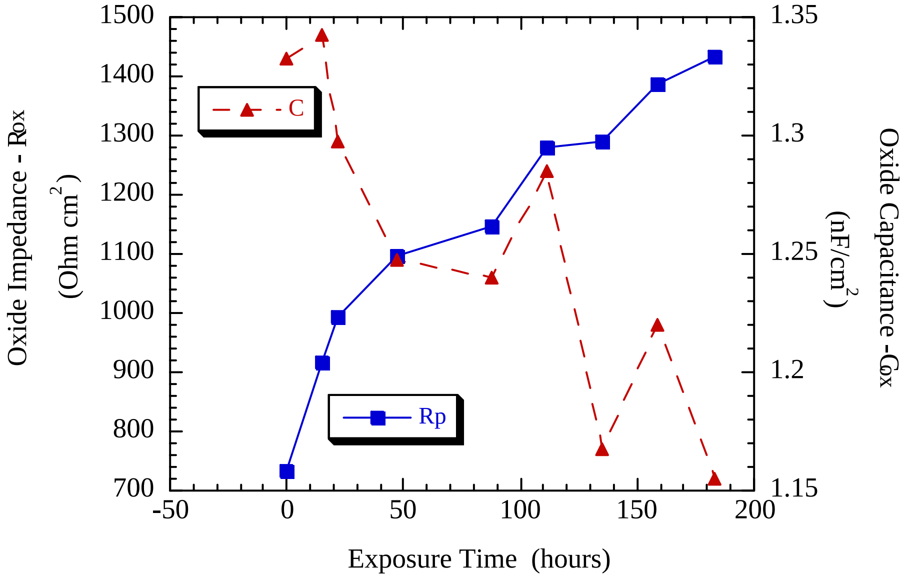
Theoretical Bode magnitude and phase data



An applied ac voltage (10 mV) across the oxide interface via a potentiostat & FRA

Experimental Characterization of Pre-oxidized HT-9 in LBE

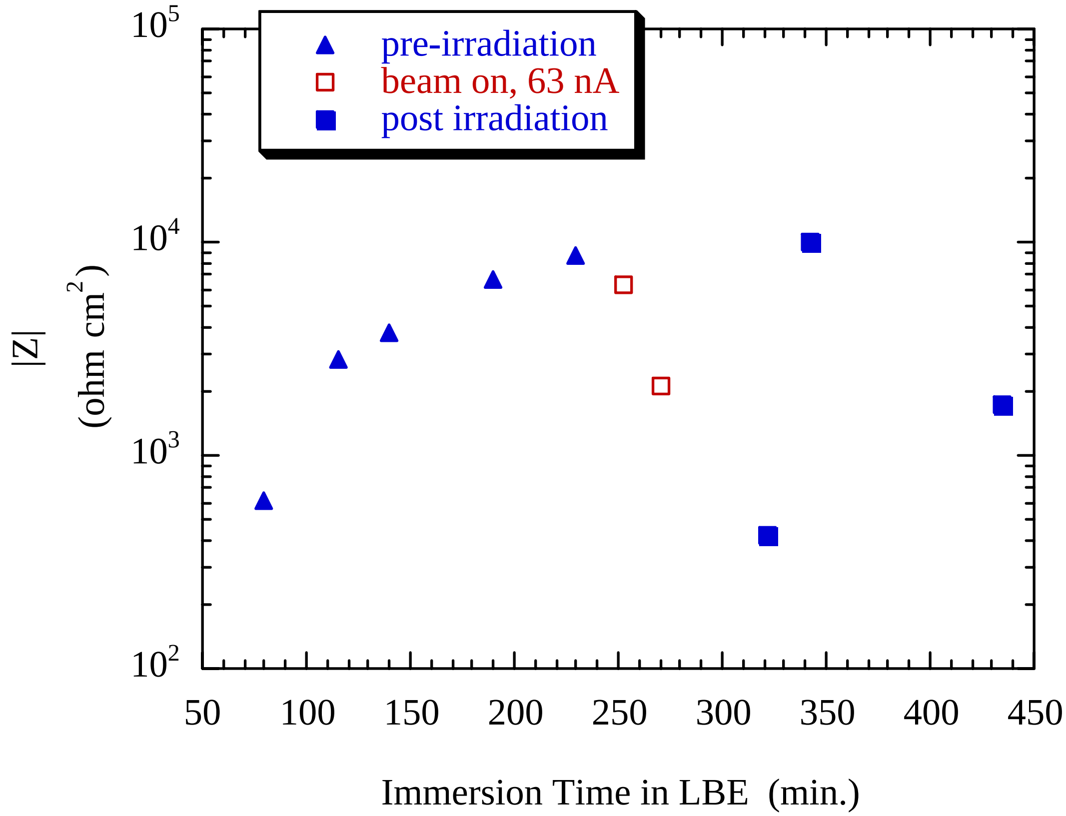
Influence of immersion time in LBE*



oxidation rate calculated from oxide impedance (conductivity) and Wagner's oxidation theory

Pre-oxidation Time (hrs.)	Pre-oxidation Thickness (μm)	LBE Immersion Time (hrs.)	Post LBE Immersion Thickness (μm)	R_{ox} (Ω·cm2)	Oxidation Rate μm/hr.
36	15	24	24	817	0.97
48	13	24	24	881	0.89
64	29	183	45	1434	0.55

Influence of Proton Irradiation on Corrosion Rate During Immersion in LBE - Pre-oxidized HT-9

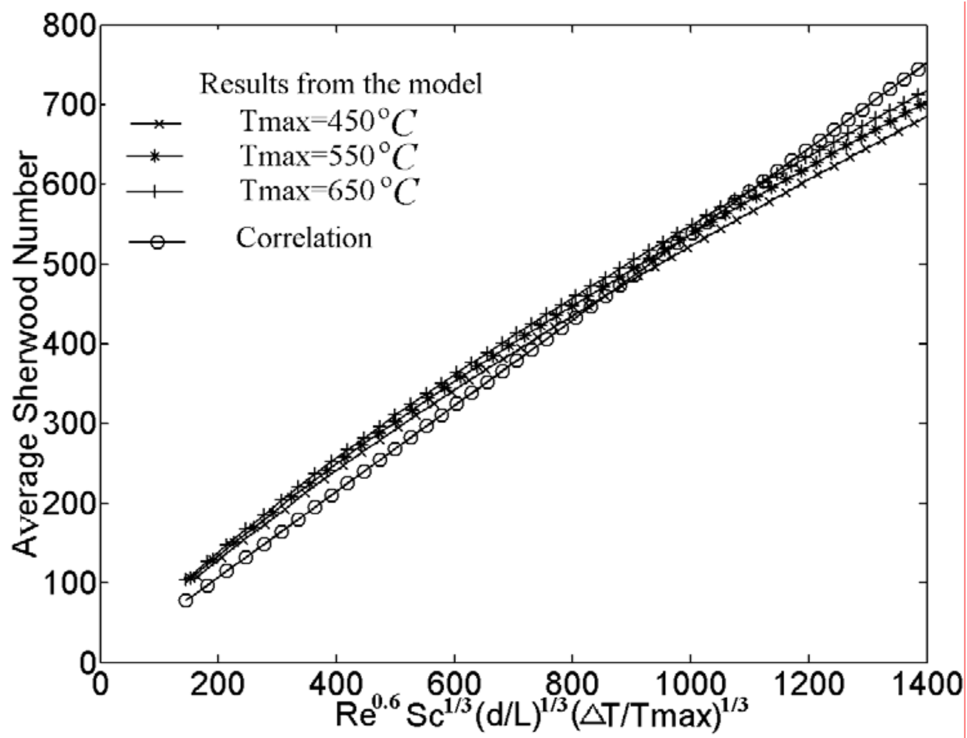


R_{ox} = Corrosion rate

Modeling Corrosion in Oxygen Controlled LBE

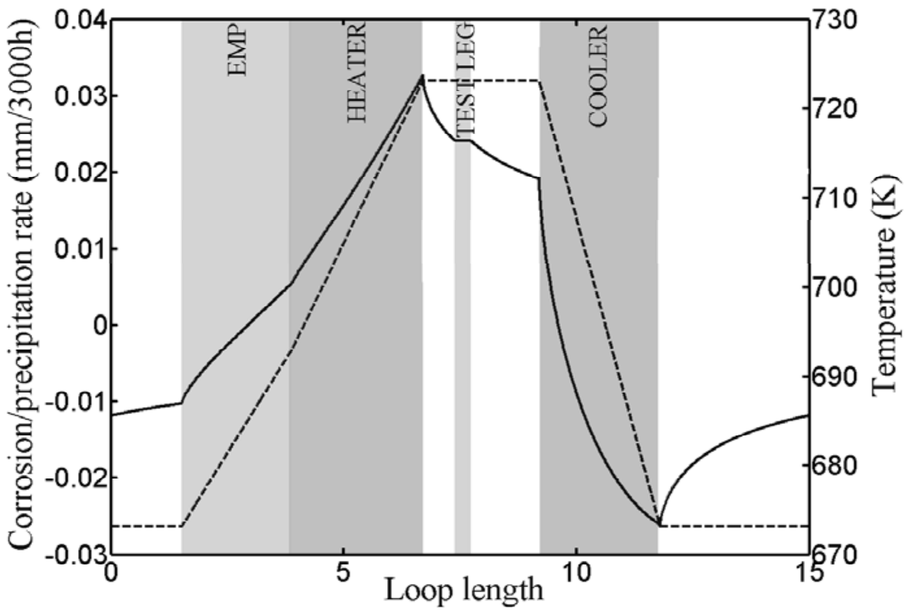
- Developed an explicit correlation of corrosion rate dependence on loop conditions (averaged in the highest temperature leg)

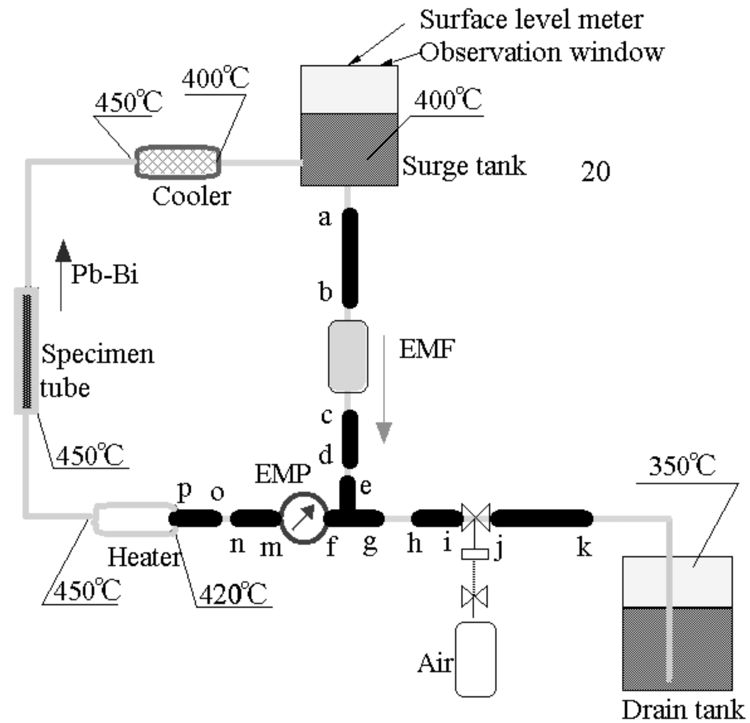
$$Sh_{av} = 0.53 Re^{0.6} Sc^{1/3} (d/L)^{1/3} (\Delta T/T_{max})^{1/3}$$



Application of Corrosion Model to JLBL-1 (JAERI Lead-Bismuth Loop) Experiment

Calculated corrosion/precipitation rate for iron (solid line) and the temperature profile (dashed line) for JLBL-1 loop.



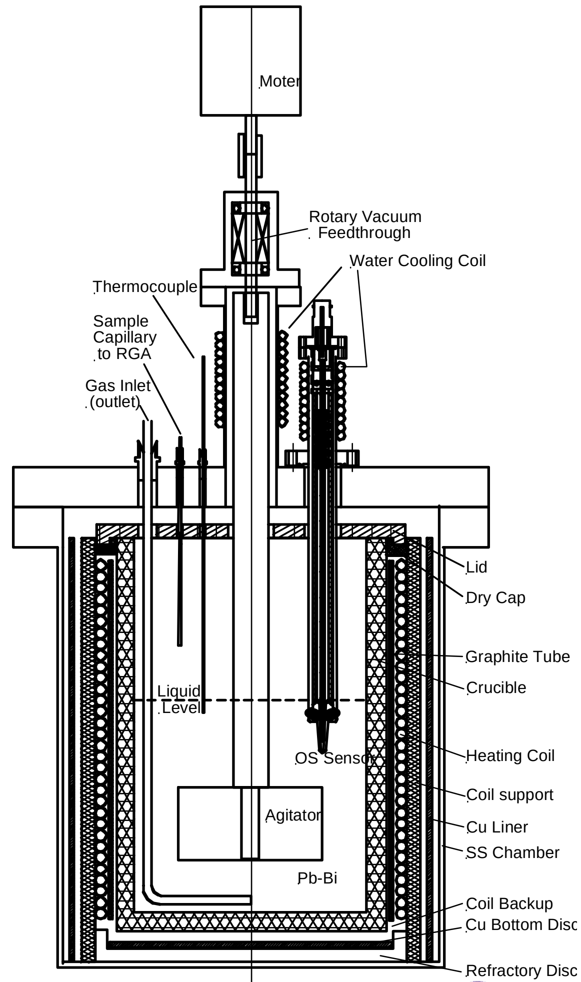


Deposition zone (thick back line) JLBL-1 experiment. The corrosion rate is between 0.03-0.1 mm at the highest temperature leg.

Design and Fabrication of New Oxygen Sensor Assembly and Calibration Stand

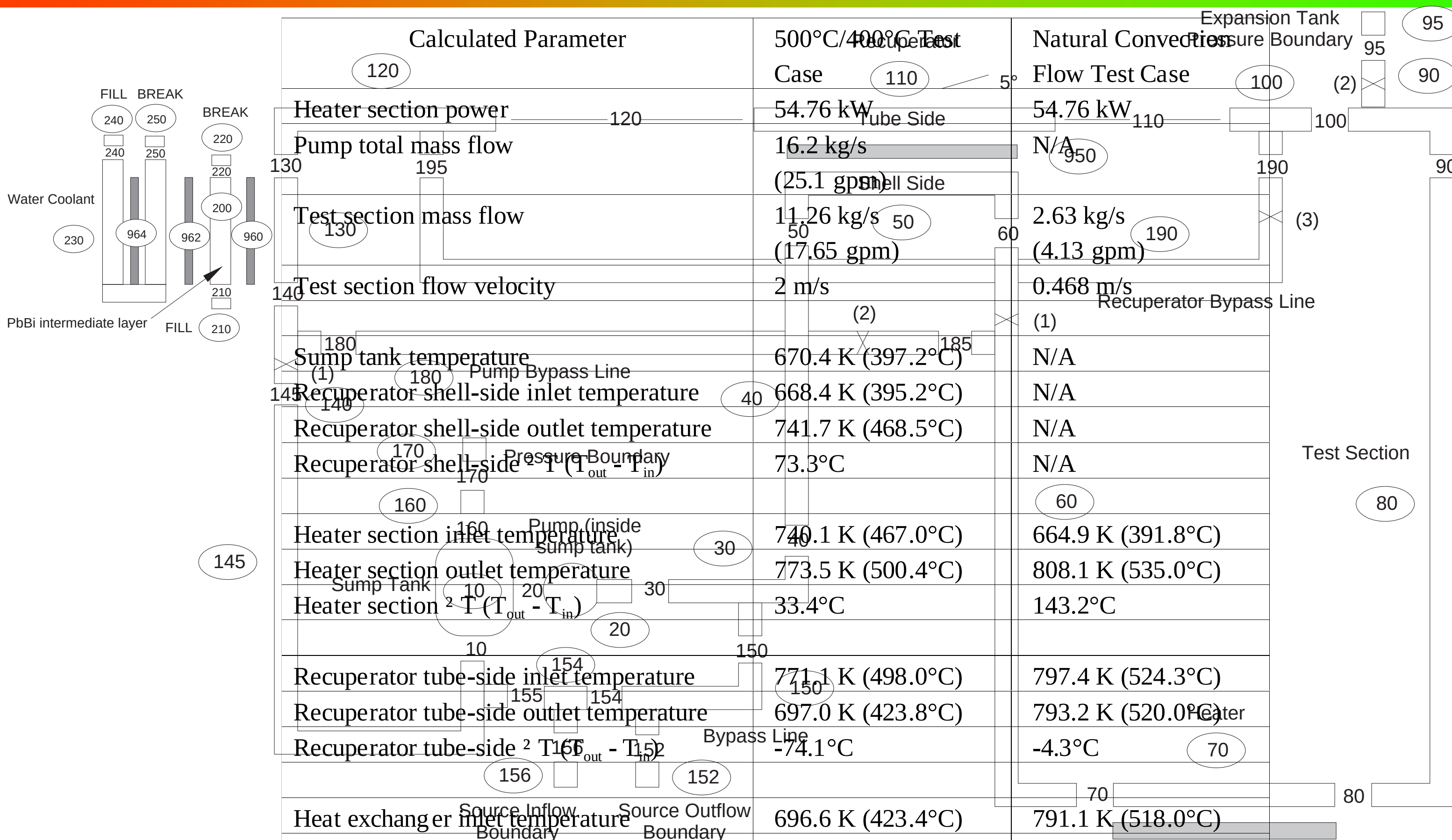
- New oxygen sensor configuration to improve assembly and removal
- New calibration stand for multiple sensor testing and higher temperatures

QuickTime™ and a Photo - JPEG decompressor are needed to see this picture.



Using TRAC Model of DELTA Loop to Set Pre-test Conditions of Natural Convection Experiment

Calculated Parameter	500°C/400°C Test Case	Natural Convection Flow Test Case
Heater section power	54.76 kW	54.76 kW
Pump total mass flow	16.2 kg/s (25.1 gpm)	N/A
Test section mass flow	11.26 kg/s (17.65 gpm)	2.63 kg/s (4.13 gpm)
Test section flow velocity	2 m/s	0.468 m/s
Sump tank temperature	670.4 K (397.2°C)	N/A
Recuperator shell-side inlet temperature	668.4 K (395.2°C)	N/A
Recuperator shell-side outlet temperature	741.7 K (468.5°C)	N/A
Recuperator shell-side ΔT (T_{out} - T_{in})	73.3°C	N/A
Heater section inlet temperature	740.1 K (467.0°C)	664.9 K (391.8°C)
Heater section outlet temperature	773.5 K (500.4°C)	808.1 K (535.0°C)
Heater section ΔT (T_{out} - T_{in})	33.4°C	143.2°C
Recuperator tube-side inlet temperature	771.1 K (498.0°C)	797.4 K (524.3°C)
Recuperator tube-side outlet temperature	697.0 K (423.8°C)	793.2 K (520.0°C)
Recuperator tube-side ΔT (T_{out} - T_{in})	-74.1°C	-4.3°C
Heat exchanger inlet temperature	696.6 K (423.4°C)	791.1 K (518.0°C)
Heat exchanger outlet temperature	673.0 K (399.9°C)	672.0 K (498.8°C)
Heat exchanger ΔT (T_{out} - T_{in})	-23.6°C	-119.1°C
Heat exchanger heat removal rate	37.48 kW	44.23 kW
Piping external heat losses	17.28 kW	10.53 kW



Valve positions:
(1) open for normal operation, closed for natural convection operation
(2) closed for normal operation, open for natural convection operation
(3) normally closed for both normal and natural convection operation but can be opened to bypass recuperator for natural convection operation

Expansion of Test Materials and Configurations

- Fe-Cr-Si alloys - Cr, Si alloying effects on LBE corrosion resistance (assisting formation of protective oxides)
- Fusion alloys
- C-rings and U-bends

University Collaborations

- U. Michigan - completed 3 MeV proton irradiation of HT-9 and T91 up to 10 dpa (study microstructure changes to simulate radiation damages in spallation environment)
- U. Illinois, U-C - nearly completed assembly of an LBE loop with EIS instrumentation to study feasibility of corrosion probes
- IAC - designing e-beam irradiation of oxygen sensors to study rad-hardiness
- MIT - Fe-Si, Fe-Cr-Si alloys, ODS, for enhanced corrosion resistance
- U. Florida - planning irradiation of oxides to study corrosion resistance under radiation
- UNLV -
  - Delivered C-rings and U-bends - SCC and liquid metal embrittlement
  - Comparing in-LBE and in-air oxidation, and studying effects of initial surface conditions
  - Modeling corrosion coupled with hydrodynamics - geometry effects
  - Setting up a test apparatus to investigate alternative use of oxygen sensors

International Cooperation

- Contributing to DOE/CEA collaborations (Work Package 3)
- Completed FZK Oxygen Control System(OCS) reception, installation and testing
- Participating in OECD/NEA LBE Expert Group: determined the scope, schedule and assignments for LBE materials handbook; and leading preparation of an international joint development plan
- Setting up ISTC 2083p agreement with IPPE to support the UNLV LBE test loop operations
- Using corrosion model to interpret JAERI test results

FZK Oxygen Control System Received and Tested

- Delivered in 5/03: successfully installed, tested and demonstrated
- Will be used for sensor calibration, and control for materials test stand

Conclusions

- The LBE technology development thrust is integrated with Gen IV LFR/SSTAR materials development program; joint planning benefits both programs
- Difficulties in cleaning the DELTA Loop of the excess oxides and oxygen are delaying the corrosion test, and moved a later development task - coolant cleaning and loop restoration - forward
- We made significant advances in several areas of coolant technology and materials development
- We continue extensive university and international collaborations